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Diffusion of Modern Irrigation Technologies in Reunion Island: An Evolutionary Approach¹

Lionel Richefort

Ph.D. Candidate and corresponding author

CIRAD² - UMR G-EAU³ and CERESUR⁴

University of Reunion Island

Station de la Bretagne, BP20, 97408

Saint-Denis Messagerie Cedex 9, Ile de la Réunion, France

Phone: +262 2 62 52 8020

Fax: +262 2 62 52 8021

E-mail: lionel.richefort@cirad.fr

Stefano Farolfi

Researcher

CIRAD – UMR G-EAU and CEEPA⁵ – University of Pretoria

University of Pretoria

CEEPA, Dept. of Agricultural Economics

0002 Pretoria

South Africa

Phone: +27 12 420 4659

Fax: +27 12 420 4958

E-mail: stefano.farolfi@cirad.fr

Jean-Louis Fusillier

Researcher

CIRAD – UMR G-EAU

Avenue Agropolis, TA 60/02

34398 Montpellier Cedex 5

France

Phone: +33 4 67 61 7506

Fax: +33 4 67 61 7506

E-mail: jean-louis.fusillier@cirad.fr

Abstract

We develop an evolutionary economics framework designed to assess the diffusion and adoption processes of modern, water-saving, irrigation technologies among heterogeneous farmers over time. This framework is evaluated using a survey on 114 farms located in Reunion Island, France. We show that the technological trajectory for irrigation equipment is related with a shift in the technological paradigm from water resource saving consideration to farm's profitability in a context of economic

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² French Agricultural Research Center for International Development.

³ Joint Research Unit, Water Management: Players and Uses.

⁴ Center for Social and Economic Research of the University of Reunion Island.

⁵ Center for Environmental Economics and Policy in Africa.

crisis for agriculture. We also show that the diffusion of the new drip irrigation technology could not only be triggered by economic incentives as subsidies. The fleeting expansion of drip irrigation seems due to a lack of institutional support in training and promoting efficient management tools.

Introduction

In the irrigated agricultural sector of Reunion Island (France), technological change is an important process supported by public funding for economic and environmental reasons such as improving productivity of sugarcane farmers and saving water resource. But farmers delay the adoption of modern irrigation technologies while these proved to be more profitable and favour only two types of irrigation systems (integral cover sprinkler and drip irrigation) whilst other techniques are available (e.g. travelling gun sprinkler) (Fusillier & al., 2006). Both environmental and agricultural policies aim at improving the cost-benefit ratio of farmer's technological adoption by subsidizing investments. These subsidies, though, do not seem to stimulate sufficiently the process of technological innovation in the irrigation sector. Institutional factors might be the reason of this technological inertia: the quasi monopoly structure of the irrigation technology market might capture farmers' surplus and extension services may influence farmers' choices.

In the literature, this problem has first been discussed by sociologists who derived some general statements about the diffusion and adoption processes of a new technology (Rogers, 1962). These early works provide a basis for the diffusion of innovation theory, developed through the use of conceptual tools derived from neoclassical economics. The first model to emerge was the epidemic diffusion one, which focuses on imitative behaviour and bandwagon effects to explain patterns of aggregate diffusion through the population of (homogeneous) potential adopters over time (Griliches, 1957; Mansfield, 1961). This model is based on a differential equation that represents a S-shaped curve and reflects the technological diffusion at a collective level. Most of the empirical research in this area has been concerned with the integration of economic parameters that may affect the speed and the ceiling of the diffusion process (Chow, 1969; Dinar & Yaron, 1992; Kemp, 1997). However, the epidemic diffusion model fails to explain why some individuals adopt earlier than other ones.

This limitation leads to the development of the rational choice model of adoption which focuses on micro-parameters of technology adoption by individuals maximizing utility (Domencich & McFadden, 1973; Caswell & Zilberman, 1985). Theoretically, the representative individual will adopt a new technology if it is rational to do that, i.e. if the expected utility with adoption is greater than the expected utility without adoption. In other words, each technology gives a specific level of satisfaction that determines individual's choice. Empirically, numerous studies have estimated a linear utility function that can vary with individuals and technologies characteristics (Feder & al., 1985). More recently, some empirical applications have tried to incorporate dynamic aspects in the estimation by focusing on factors that reflect the stochastic structure of the utility function and sunk costs of the decision to adopt (Kemp, 1997; Carey & Zilberman, 2002; Koundouri & al., 2006). Nevertheless, a reduced form of the model is always estimated and strong assumptions are always made on the form of the utility function due to lack of data.

On the other hand, within the evolutionary theory of technological change pioneered by Nelson & Winter (1982), the analysis of technological diffusion took a different direction. This paradigm has been concerned with the impact of endogenous changes that can occur during the diffusion and adoption processes by assuming that technologies are dynamically linked to other technologies, users' practices and institutions. More precisely, the evolutionary economics approach attempts to recognize the way in which a sector is locked-in to particular (un)sustainable technologies (Dosi, 1982; 1988; David, 1985; Arthur, 1989; Kemp, 1997). The present paper refers to this theory by analysing in depth the interactive learning process between farmers and institutions to explain this phenomenon. We will adopt the evolutionary economics toolbox to illustrate and discuss the technological trajectories for irrigation in the sugarcane sector of Reunion Island over the 1975-2005 period. A sample of 114 sugarcane farmers was surveyed to this purpose.

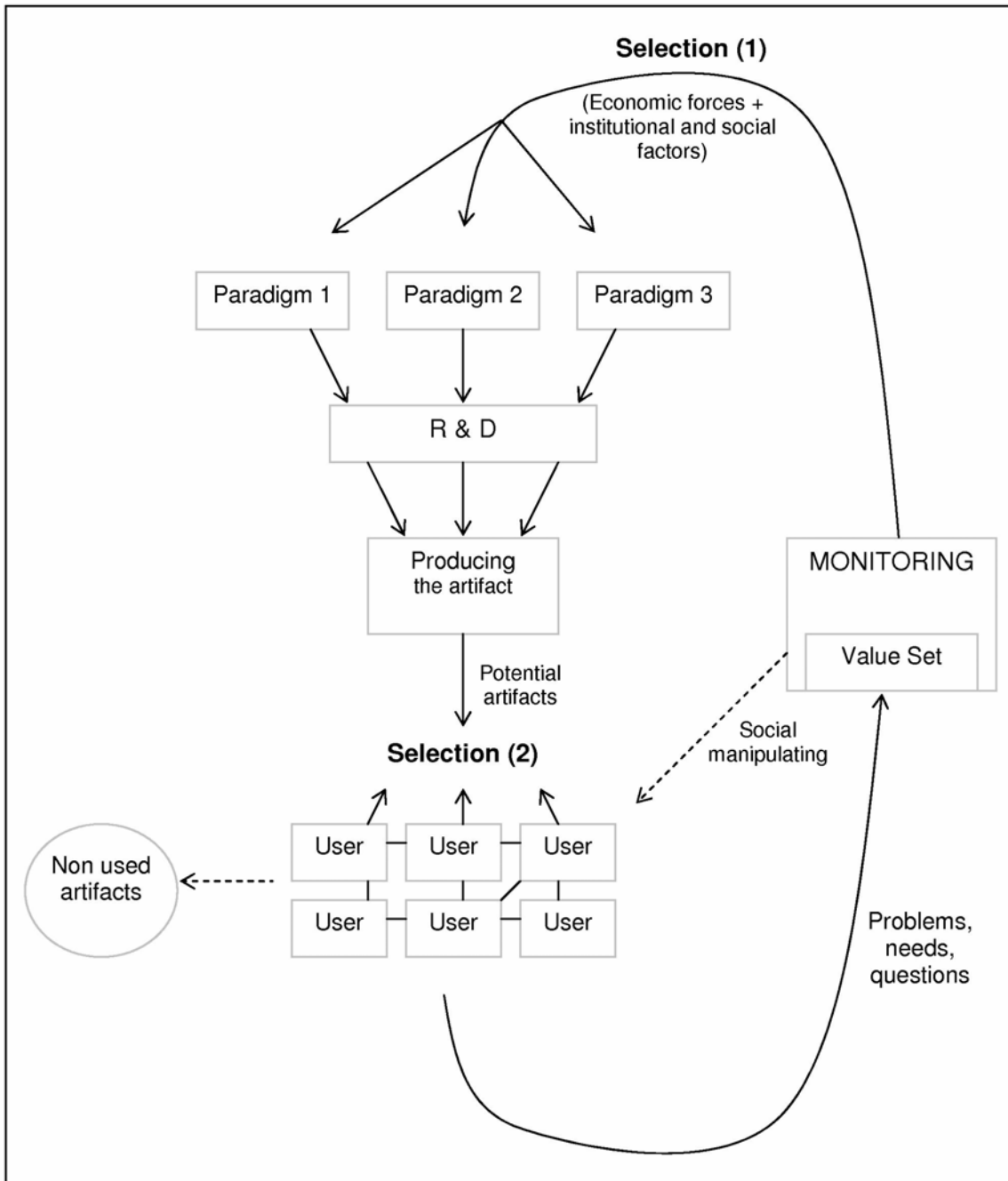
The rest of the paper is organised as follows. In section 2, we develop the conceptual framework. In section 3, we describe the data and the empirical procedure. In section 4, we present and discuss the empirical results. We conclude in section 5 by deriving some recommendations for policy makers and showing the added value of evolutionary economics to this particular case study.

Conceptual framework

The starting point of evolutionary economics as an alternative and complementary theory to neoclassical economics comes from the difficulty of building a relevant neoclassical growth theory with dynamic micro foundations (Nelson & Winter, 1974; 1982). As early stated by Veblen (1909, p.629): "Not only is the individual's conduct hedged about and directed by his habitual relations to his fellows in the group, but these relations, being of an institutional character, vary as the institutional scheme varies. The wants and desires, the end and aim, the ways and means, the amplitude and drift of the individual's conduct are functions of an institutional variable that is of a highly complex and wholly unstable character".

The evolutionary economics framework is built on a translation of the notion of scientific paradigm from Kuhn (1962) to a technological analogy: a technological paradigm. It is defined as: "an outlook, a set of procedures, a definition of the relevant problems, and of the specific knowledge related to their solution" (Dosi, 1982). The technological paradigm is made by both a product to improve (the "artefact") and a set of heuristics (Where are we going? Where should we search? What sort of knowledge should we use?) (Dosi, 1988). Basically, it consists in improving the performances and reducing the costs of a specific technology (for instance an irrigation technology). A very important point to note is that the direction of advance is programmed within the paradigm itself. This is called a "technological trajectory". Thus, the crucial question is to understand how an established paradigm emerge in the first place, how it is preferred to other possible ones?

The first level of selection may operate on the basis of economic rationality in order to choose a specific technological paradigm. Consequently, "economic forces" together with institutional and social factors may operate as a selective device (Dosi, 1988). Furthermore, Giovanni Dosi specified that: "once a path has been selected and established, it shows a momentum of its own". This enforces the direction towards which the "problem solving activity" moves. This notion is called a "natural trajectory" of technological progress (Nelson & Winter, 1982). Two selection layers can be distinguished: first the institutional one and second the market one. The first one is ex ante the second one is ex post. More precisely, the economic and social environment affects technological development in two ways: first, selection of the direction of mutation (i.e. the selection of the technological paradigm) and second, selection among mutations in a more Darwinian matter (i.e. the ex post selection among Schumpeterian trails and errors) (Freeman, 1991; Metcalfe, 1994). The evolutionary framework of technological change is presented in figure 1.



(Sources : Nelson & Winter, 1982; Dosi, 1982; 1988)

Figure 1: The evolutionary framework of technological change

This conceptualization leads to an important question for economic theory: how organizations (firms, institutions, R&D and policy makers) react to the selection of a technological paradigm and how all interactions within this global technological system evolve and affect progress among a technological trajectory?

In fact, the outcome of a technological paradigm will often not converge towards a unique equilibrium but instead reaches one of several equilibria (David, 2000; Wilkins & Swatman, 2006). This dynamic vision of economic evolution is very different from the neo-classical economics tradition, which in its simplest form assumes that only a single outcome could possibly be reached, regardless of initial conditions or transitory events (Bromley, 1982; Vatn, 2006). Furthermore, it is well known that organizations can make incorrect technological choices because of their beliefs on what is feasible or at least worth to attempt (Simon, 1959). Particularly, the dynamics of learning for policy makers,

institutions, firms and R&D is a central parameter of potential lock-ins (David, 1985; Arthur, 1989; Montaigne, 1997; Saviotti, 2001). This framework has recently been applied to the adoption of environmental beneficial technologies and allow to identify the reasons that push some organizations to make suboptimal technological choices (i.e. to select a technological paradigm bad-fitted to their environment) (Kemp, 1997; Mulder & al., 1999; Farolfi & Montaigne, 2001; Perret & Stevens, 2006).

Data description and empirical procedure

Data description

The data used for this study were collected via a survey conducted in Reunion Island in 2006. This sample was drawn through the stratified sampling method using a broader data set built by the CIRAD six years ago⁶. The strata were represented by the spatial location of farmers and their water consumption level. The sample describes the evolution of irrigation technologies for 114 farmers from 1987 to 2005. According to this survey, the adoption of sprinkler with integral cover system (fixed sprinkler) and drip irrigation started both during the late 1980's. The adoption of integral cover system was characterized by a slow start followed by a progressive acceleration from the late 1990's until now whereas the diffusion of drip irrigation, after a slow start, experienced a progressive abandonment from the late 1990's until now. The dynamics of the adoption of these two technologies are illustrated in figure 2.

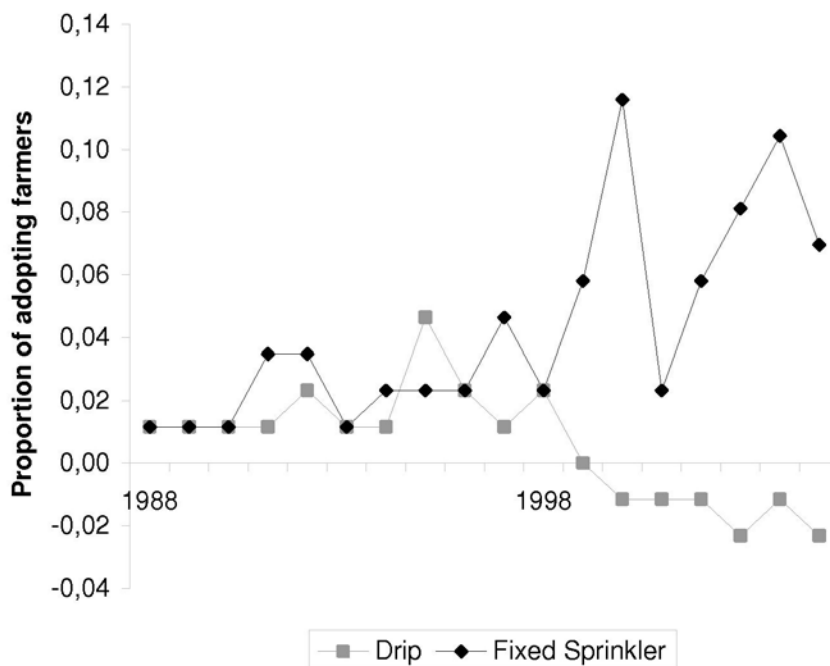


Figure 2: The adoption of modern irrigation technologies in Reunion Island, 1988-2005

As shown in table 1 containing the main descriptive statistics⁷ derived from the sample and referred to 2005, the farmers adopting either drip or integral cover system technologies are younger, more

⁶ This broader data set combines data from several local institutions involved in irrigated agricultural management.

⁷ The variable "cultivated surface" variable concerns the irrigated and non irrigated surfaces owned by farmers. The variable "age" represents farmers' age at the time of the survey. The variables "sugarcane yield" and "water consumption" are averages per hectare and per year. The variable

educated and better trained than non adopters. They also have a higher total surface, a higher sugarcane yield, a lower water consumption, better irrigation practices (or a higher frequency of irrigation), a higher risk tolerance (or bear more risk on profit) and a higher involvement in social networks than non adopters.

Table 1: Descriptive statistics (year = 2005, n=114)

	Obsolete	Fixed sprinkler		Drip	Adoptio n with abandon
		Early adopters	Late adopters	Adoption without abandon	n
	n=23	n=26	n=48	n=13	n=6
Cultivated surface (ha)	5,8	10,6	7,9	12,6	9,9
Age (year)	51	45	44	53	43
Sugarcane yield (t/ha/year)	96,5	103,5	104,9	104,6	109,2
Water consumption (m3/ha/year)	10793	8378	7680	6194	5211
Irrigation practices (days)	11,4	6	6,1	1,5	5,8
Income risk tolerance [1;3]	1,1	1,5	1,6	2,5	2,7
Initial training [0;1]	0,2	0,1	0,4	0,4	1
Involvement in social networks [0;1]	0,3	0,6	0,2	0,4	0,2
Spatial distribution [0;1]	0,6	0,5	0,8	0,3	0,2
Extensions services [0;3]	0,7	0,9	1,1	1,5	0,7

The farmers adopting integral cover system⁸ technology are younger, less educated and less advised than the farmers adopting drip irrigation⁹. They also have a lower cropping surface, higher water consumption, a lower frequency of irrigation, a lower income risk tolerance and a higher involvement in social networks than the farmers adopting drip irrigation.

“irrigation practices” reflect the frequency of water provision to crops. The income risk tolerance is approximated by the degree of diversification (from 1, no diversification, to 3, well diversified) as it has been proven that diversified crops (cattled farming, truck farming, ...) implies more risk on profit than monoculture sugarcane (Fusillier & al., 2006). The variables “initial training” and “involvement in social networks” are dummies. The variable “spatial distribution” is a ratio between the number of micro zones where a given technology is present and the total number of micro zones, as the irrigated areas have been previously divided in 24 homogeneous pedoclimatic micro zones. The variable “extension services” illustrate the type of advices received by farmers (from 0, no advice, to 3, sophisticated advice).

⁸ Integral cover system technology is widespread in the whole irrigated area. Early adopters of this technology (those who adopted before 2000) were younger at the time they adopted than late adopters. Furthermore, they are less educated and less advised than late adopters. They also have a higher cultivated surface, a lower sugarcane yield, higher water consumption and a higher involvement in social networks.

⁹ Drip irrigation is located on only one third of the irrigated area as this technology have been promoted in dryer and windy areas. Adopters who didn't abandon this technology are older, less educated and more advised than adopters who abandon it (in order to switch towards fixed sprinkler irrigation). They also have a higher cultivated surface, a lower sugarcane yield, higher water consumption, lower income risk tolerance and a higher involvement in social networks.

The empirical procedure

The method adopted in this study consists in the mobilization of evolutionary economics concepts to interpret the field data about irrigation technology obtained through the survey previously exposed.

We first illustrate the evolution of the technological paradigm of irrigation by linking it to relevant historical events. We therefore check if a new technological paradigm has emerged or not and emphasize the key factors of this potential mutation. Then, we focus on the process of the technological development in the irrigation sector. We particularly depict the trajectory of sprinkler and drip irrigation from 1975 until now and explain potential shifts in the technological trajectory by linking it to the evolution of the technological paradigm. Finally, we discuss the microeconomic effects of this technological development and its impacts on the institutional context of technological change in the irrigation sector.

Results

Evolution of the technological paradigm of irrigation

Irrigation schemes have been implemented in Reunion Island since the 1970's to increase the local sugarcane production and the productivity of arid areas. During the 70's and early 80's, sprinkler with portable nozzle line or total cover system were the only technologies promoted on the irrigated areas. This was essentially to reduce the costs for irrigation equipment.

This paradigm evolved during the 1980's towards more water-saving considerations and productivity-oriented considerations. This was due to the introduction of new irrigated schemes in dryer areas. This situation led institutions to promote drip irrigation, integral cover system for sprinkler and sophisticated irrigation scheduling tools based on water balance models. The basic idea was to provide incentives for a quick technological change for farms (Chastel, 1989).

Then, in the 2000's, improving the productivity of sugarcane became the critical issue. This was motivated by a decrease in the surface and production of sugarcane facing urban extensions, a threat of closing the sugar factory and the renegotiations of the European policy about the sugar sector. This led institutions to allocate new resources for the adoption of more robust technologies (sprinkler with integral cover system and simplified extensions services). It is evident that both objectives consisting in saving water and supporting the local agricultural production have always co-existed. It seems nevertheless that the present burning priority is to save the agricultural sector considering the seriousness of internal threats (sudden jumps in production costs) and external threats (progressive sector de-regulation). Water is seen as a rare factor of production under local control which should not penalize further an already suffering agricultural sector¹⁰.

The technological trajectory of irrigation

The evolution of the technological paradigm of irrigation implied a trajectory of irrigation technologies that is depicted in figure 3. Sprinkler has evolved from mobile or total (semi mobile) cover systems to integral cover system (fixed sprinkler). This improvement on sprinkler irrigation started during the 1980's. At the same time, drip irrigation started to be selected when the technological paradigm moved towards more water-saving objectives and with the introduction of new irrigated areas in dryer lands.

This was followed by a phase of learning by using. A result of this phase was that a shift from sprinkler to drip irrigation needed a deep change in farmers' practices and in extension services. This change would have required a too long and costly training phase for both farmers and institutions. Furthermore, the cost of investment was too high because of the necessary change of tertiary pipes during each replacement of sugarcane roots (generally every 7 years). At the same time, the transition from (semi) mobile sprinkler to fixed sprinkler didn't require such a learning phase, as farmers and institutions were already aware of the practices associated with sprinkler. This fact led to a progressive

¹⁰ Two measures illustrated this pro-agriculture policy concerning water resource regulation decided by local authorities: a) the decision to apply to the agricultural sector the minimum level of tax allowed by the French water law for taking water out from its natural element and b) the decision to lock the irrigation water price since 1999 (Fusillier & Saqué, 2003; Fusillier & al., 2006).

abandonment of drip irrigation in the 2000's when the technological paradigm moved towards an increase attention on crops' productivity.

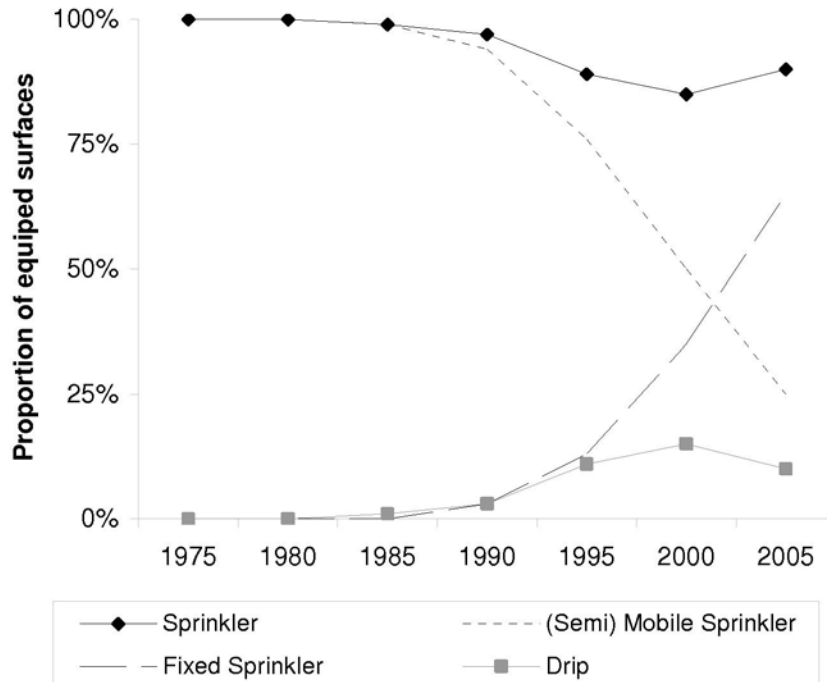


Figure 3: The trajectory of irrigation technologies in Reunion Island, 1975-2005

The institutional framework

The institutional context of the process of technological change in the irrigation sector is provided in figure 4. The first selection level of the technology is realised by two institutions: the departmental authority called Conseil Général (CG) and the state's service for agriculture and forestry (DAF). They select the technological paradigm of irrigation according to the evolution of the agricultural development strategy, the evolution of the water policy and social pressure (increasing needs in domestic water). Two technological paradigms are described in figure 4: one where the priority is given to saving water (related to drip irrigation) and another one where the priority is given to improving agricultural production and productivity (related to improvements on sprinkler irrigation).

Once the technological paradigm has been selected, the agronomic research (CIRAD) adjust new technologies for irrigation equipment and scheduling tools. Then, in a top down diffusion way, the chamber of agriculture (CA), following research recommendations and results, provides training and extension services to farmers. Problems of cost and labour productivity with drip irrigation, needs of training and questions about the evolution of sugar and water prices come back from farmers to the monitoring institutions (CG and DAF), who can decide to select a new technological paradigm or to re-orient the current one. The monitoring institutions influence concretely farmers by providing subsidies to the investments and to the sugarcane production.

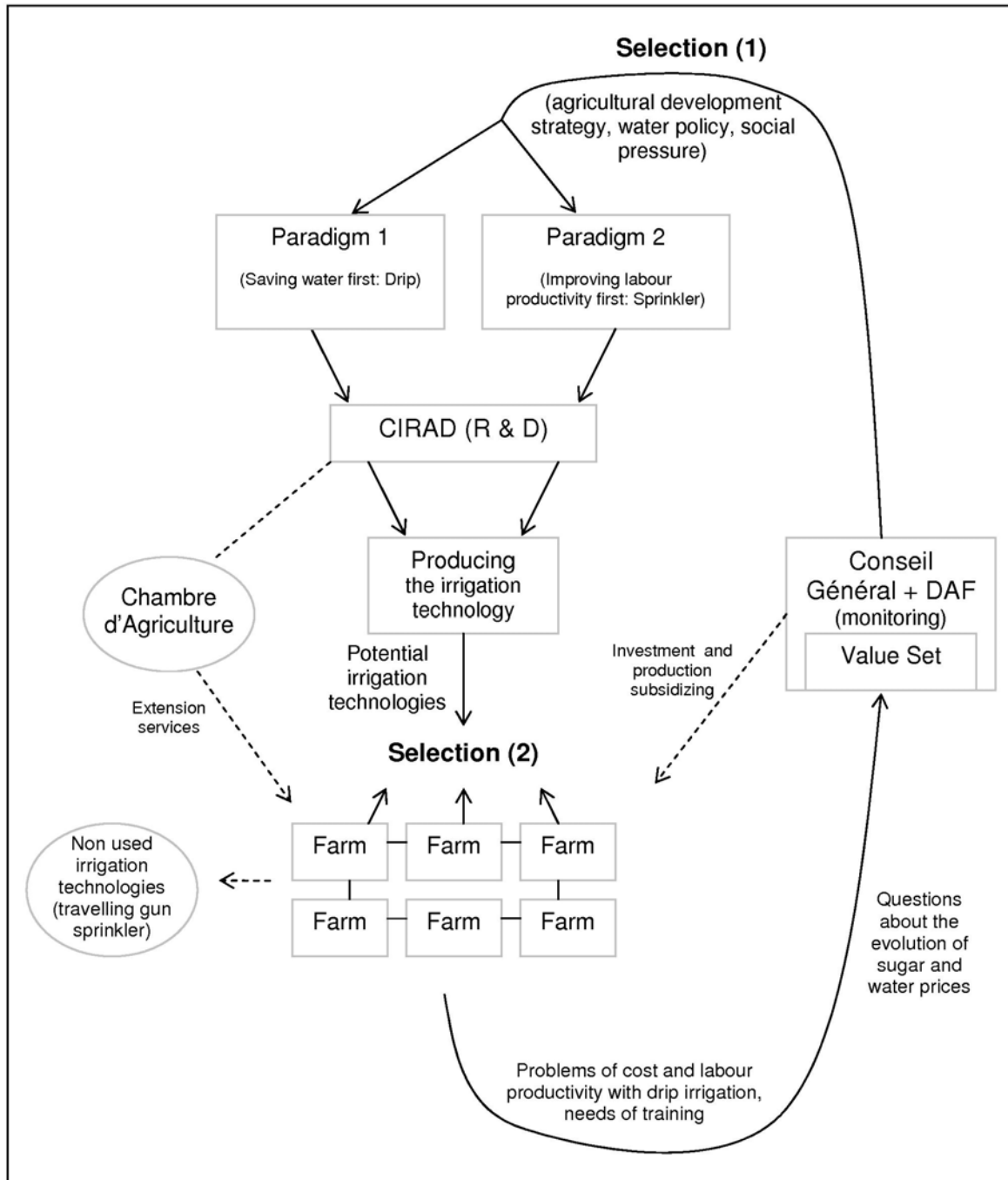


Figure 4: The institutional context of innovation in the irrigation sector of Reunion Island

One interesting point to note is that farmers are technically and administratively influenced by several institutions. This can be the source of coordination problems. It led to the creation of the technical committee for irrigation (Comité Technique pour l'Irrigation, CTI), which decides whether to provide or not an investment subsidy to farmers who ask for it. Composed by members from the CG, the DAF and the CA, the CTI plays an important role at the second selection level and deeply affects the selection environment of farmers. Consequently, the effects of investment subsidies may not follow the neoclassical conclusions derived under the assumption of perfect competition for the irrigation technology market and be sufficient, thus, to provide incentives for specific technological adoptions.

Another interesting point to note and which will be developed in further research is the role played by the local plastic industry that provides irrigation pipes at the second level of selection.

Conclusions

This research attempted to develop and discuss an evolutionary economics framework to assess the diffusion of modern, water-saving, irrigation technologies over time in Reunion Island.

We first developed an evolutionary economics framework to conceptualize the diffusion and adoption processes of environment-conserving technologies. This framework was then applied to the diffusion of modern irrigation technologies (fixed sprinkler irrigation and drip irrigation) in the sugarcane sector of Reunion Island. By interpreting descriptive statistics obtained from a survey on a sample of 114 sugarcane farmers through the evolutionary economics concepts, we found that the technological trajectory for irrigation equipment is related with a shift in the technological paradigm from water resource saving consideration to farm's profitability in a context of economic crisis for agriculture.

By taking an explicit dynamic perspective, the evolutionary economics framework can help to understand the origin of technological choices that may be misunderstood by neoclassical models. As a consequence, factors that represent pure technical problems in the neoclassical world become decisive. Particularly, the dynamics of learning for both institutions and farmers may affect the selection environment of farmers, thus showing that investment subsidizing or extension services will not be sufficient to sustain shifts towards more water-saving trajectories.

Furthermore, the evolutionary economics framework helps to understand the origin of variations in the dynamics of adoption. Particularly, the added-value of the evolutionary economics approach lies on the possibility to explain the fleeting expansion of drip irrigation by linking it to the institutional context of technological change in the irrigation sector of Reunion Island.

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